ASSESSING POTENTIAL RISKS FROM EXPOSURE TO NATURAL URANIUM IN WELL WATER : NAMBE, NEW MEXICO

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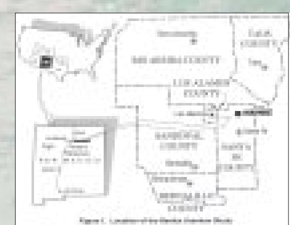
ABSTRACT

Over 50% of the wells in the Nambe region of northern New Mexico exceed the U.S. Environmental Protection Agency's recommended drinking water standard of 20 μg L^{-1} (ppb) for ^{238}U; the highest in the area was measured at 1200 μg U L^{-1}. The purpose of this study was to estimate the radiological and toxicological doses from the (1) ingestion of well waters, (2) consumption of four common vegetable species (tomato, squash, lettuce, and radish), and (3) inhalation of resuspended soil irrigated with well waters varying in U concentration (<1, 150, 500, and 1200 μg U L^{-1}). Net average U concentrations in irrigated soil and vegetables increased linearly with increasing U levels in irrigation water, and the general order of U uptake between plant species was radish≥lettuce>squash>tomato. The estimated committed effective dose for 70 years of maximum continuous exposure, via the three pathways to well water containing 1200 μg U L^{-1}, was 0.17 mSv (17 mrem) with a corresponding kidney burden of 0.8 μg U g^{-1} (ppm); the radiological dose was not significant and the toxicological dose was below the 1 μg U g^{-1} kidney threshold. Ingestion of well water contributed 99% to the radiation dose and kidney burden; vegetable consumption contributed ≈1%; and, soil inhalation was insignificant.

INTRODUCTION

In 1995, the Ground Water Protection and Remediation Bureau of the State of New Mexico's Environment Department (NMED) sampled 72 private wells in the Nambe region in northern New Mexico (McQuillan and Montes, 1998) (Fig. 1). Thirty-seven (52%) of these wells contained uranium (U) concentrations exceeding the Environmental Protection Agency's (EPA) proposed limit of 20 μg U L^{-1} (USEPA, 1996). NMED found U concentrations ranging from below detection limits up to 920 μg U L^{-1}. Elevated levels of U in Nambe well water are associated with a low-grade U deposit and with the oxidizing and reducing groundwater environments found in the region (McQuillan and Pine, 1995). Soluble uranyl complexes are produced in oxidizing environments (De Vivo et al., 1984). Currently, numerous wells in the Nambe area are used as primary sources of drinking and irrigation water for home gardens. Natural U is classified as both a radiological and chemo-toxicological agent, and it is the only radioactive substance for which chemical toxicity is the limiting factor in risk assessments (Wrenn et al., 1985). Utilization of water from these wells has raised concerns of potential radiological and toxicological risks to human consumers.

The purpose of this study was to evaluate site-specific uptake of U from irrigation water, with varying U concentrations, in four common vegetable species. The data were used to estimate potential radiological and toxicological doses based on the (1) water, (2) consumption of irrigated vegetables, and (3) inhalation of resuspended soil irrigated with the well water.



MATERIALS AND METHODS

•Four wells, including one control (<1 μg U L^{-1}) and three treatment wells (150, 500, and 1200 μg U L^{-1}), were selected for study.

•Well waters were analyzed for pH, EC, Ca, Na, Mg, K, P, total U, NO_3-N, NH_4-N, TKN, carbonates, bi-carbonates, and total dissolved solids.

•Soil was collected from approximately 50 sites and mixed (Fig. 2). Four composite baseline soil samples were collected and analyzed for chemical and physical properties (Table 1).

•Sixty-four 19-L pots were filled with approximately 15 L of soil, labeled, and placed into a 4.5 by 6.0 m cage on an elevated platform (Fig. 3). Treatment pots were arranged in a complete randomized block design with four replicates using a random numbers table.

•Each block consisted of four plant species: lettuce and tomato (exposed crops), squash (protected crops), and radish (root crops).

•Plants were irrigated to field capacity with the four treatment waters (Fig 4). Produce and edible plants were collected at maturation (Fig. 5). Samples were thoroughly rinsed with tap water (<1 μg U L^{-1}), towel-dried, placed in paper bags, and dried for 48 hours at 75 °C. Samples were then ground using a Wiley mill and submitted for analysis. Vertically-mixed (composite) soil samples were collected and analyzed for chemical elements.

•A Mann-Kendall test at the 0.05 probability level (Gilbert, 1987) was employed to evaluate trends in soil chemical elements with the addition of water containing varying U concentrations. In addition, the Wilcoxon Rank sum test (Hollander and Wolfe, 1973) was used to assess differences at the 0.05 probability level in U uptake between plant species irrigated with varying concentrations of U.

•U concentrations in produce were converted to a fresh mass basis for ingestion calculations using site-specific dry/wet ratios (Fresquez and Ferenbaugh, 1999) for each species. The dose conversion factor for bone surface, rather than red marrow, was used (Durbin, 1998).

•Committed effective dose (CED) were estimated based on 1, 50, and 70 year exposures via water and produce ingestion and soil inhalation. Doses were estimated based on mean and maximum ingestion and inhalation rates as defined in the EPA Exposure Factors Handbook (USEPA, 1997).

•Maximum ingestion rate was based upon mean ingestion rates + two std dev, while the maximum inhalation rate was based on recommended factors including inhalation rate and duration of exposure (USEPA, 1997). Ingestion absorption fractions and dose conversion factors were obtained from ICRP (1995) while those relating to inhalation were obtained from ICRP (1996).

•U concentration in the kidney was obtained by converting the annual intake (Bq), estimated in the radiological dose calculations, to grams using the specific activity of U (1.24×10^4 Bq g^{-1} U). This amount was converted to μg U and then divided by reference man's kidney mass (310 g) resulting in μg U g^{-1} kidney (Shleien, 1992).

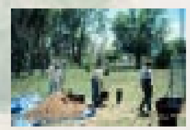
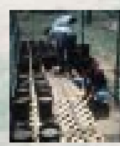


Figure 2



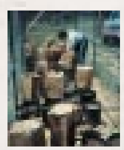
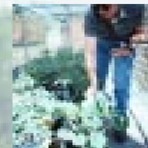
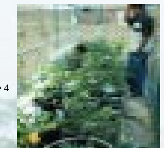


Figure 3





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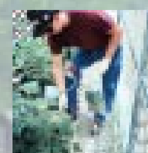

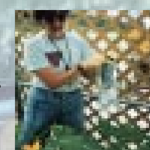

Figure 5

RESULTS AND DISCUSSION

Soil

Net average U concentrations in irrigated soil increased linearly with increasing U concentration in irrigation water. Four (Na, EC, OM, and U) out of the thirteen chemical constituents analyzed had significant differences (p<0.05) between baseline soil and soil irrigated with the three treatment waters (Table 1).

Uranium Uptake in Vegetables

The general order of U uptake between the various species was radish≥lettuce>squash>tomato (Table 2). A regression analysis showed that U uptake within species was highly correlated to U concentration in water. Observed differences in species uptake were consistent with those of Morishima et al. (1977), who found that leafy (lettuce) and root (radish) vegetables have a higher uptake of U than berries (tomato and pumpkin), and Lakshmanan and Venkateswarlu (1988), who found radish root uptake greater than bottle gourd uptake.

Radiological Dose

Based on average values of ingestion and inhalation, a CED of about 0.1 mSv was estimated for 50 and 70 year exposures to water containing 1200 μg U L^{-1} (Table 3). For maximum intake conditions, the estimated CED for 50 and 70 year exposures were 0.16 and 0.17 mSv, respectively. Drinking water contributed roughly 99% of the total dose for both mean and maximum exposure conditions to Nambe well water. Vegetable ingestion contributed approximately 1% of the dose and soil inhalation was insignificant. Over 99% of the CED resulted from dose to bone. This result is consistent with Bosshard et al. (1992) and Durbin (1998), who state that bone is the limiting tissue for radiological risk due to exposure to natural U.

Uranium Concentrations in the Kidney

Exposure to well water (via all pathways) containing up to 1200 μg U L^{-1} resulted in a kidney burden of 0.8 μg g^{-1} (Table 4). Wrenn et al. (1985) recommended using a threshold limit of 1 μg U g^{-1}. Well water ingestion contributed 99% to the kidney dose.

TABLE 1. Chemical and Physical Properties of Baseline Soil and Soil Irrigated with Water Containing Various Concentrations of Natural U

Natural U Level (μg L^{-1})	Ca (mg Kg^{-1})	Mg (mg Kg^{-1})	Na (mg Kg^{-1})	K (mg Kg^{-1})	EC (dS m^{-1})	CEC (cmol (+) Kg^{-1})	pH
Baseline[a]	157 ± 16	16 ± 2.4	52 ± 4.6	118 ± 3.3	1.4 ± 0.1	8.2 ± 1.0	7.8 ± 0.1
<1	146	17	78[b]	94	1.3[b]	19	7.6
150	171	18	143	90	1.6	21	7.7
500	129	13	258	84	1.8	19	7.9
1200	245	30	437	104	3.1	19	7.9
Natural U Level (μg L^{-1})	**P (mg Kg^{-1})**	**NO_3-N (mg Kg^{-1})**	**NH_4-N (mg Kg^{-1})**	**TKN (mg Kg^{-1})**	**OM (g Kg^{-1})**	**U (mg Kg^{-1})**	**Texture**
Baseline	20 ± 1.3	29 ± 3.3	7.3 ± 0.8	1680 ± 755	16 ± 2.5	2.3 ± 3.0	Sandy loam
<1	15	31	3.7	989	14[b]	1.6[b]	
150	15	22	3.6	946	15	1.9	
500	16	27	3.2	989	16	3.2	
1200	17	34	3.8	892	17	4.1	

[a]Baseline data include ± SD.
[b]Denotes a significantly increasing trend with increasing U levels at the 0.05 probability level using the nonparametric Mann-Kendall Trend Analysis Test.

TABLE 2. Mean (±SD) Concentrations in Edible Crop Tissue Irrigated with Water Containing Various Levels of Natural U (μg U Kg^{-1} dry weight)

Water U Concentration (μg U L^{-1})	Tomato	Squash	Radish	Lettuce
<1	8 ± 2.8C[a]	13 ± 2B	82 ± 18A	79 ± 20A
150	18 ± 3.5C	45 ± 19B	495 ± 193A	441 ± 140A
500	38 ± 1.9C	161 ± 70B	1306 ± 392A	1370 ± 191A
1200	67 ± 22.0C	285 ± 49B	2879 ± 830A	2304 ± 393A

[a]Mean within the same row followed by the same upper-case letter were not significantly different at the 0.05 probability level using a nonparametric Wilcoxan Rank Sum test.

TABLE 3. Estimated CED (mSv) for Mean and Maximum Exposure to Well Water Containing Various Levels of Natural U via Water and Produce Ingestion and Soil Inhalation

	<1 μg U L^{-1}		150 μg U L^{-1}		500 μg U L^{-1}		1200 μg U L^{-1}	
	50 Year	70 Year	50 Year	70 Year	50 Year	70 Year	50 Year	70 Year
Mean	1.1×10^{-4}	1.2×10^{-2}	1.2×10^{-2}	1.2×10^{-2}	4.2×10^{-2}	4.4×10^{-2}	9.6×10^{-2}	1.0×10^{-1}
Max.	2.4×10^{-4}	2.6×10^{-4}	2.0×10^{-2}	2.0×10^{-2}	7.0×10^{-2}	7.4×10^{-2}	1.6×10^{-1}	1.7×10^{-1}

TABLE 4. Estimated U Concentration in Kidney (μg U g^{-1}) for Mean and Maximum Exposures to Well Water Containing Various Levels of Natural U via Water and Produce Ingestion and Soil Inhalation

Duration of Exposure (yr)	<1 (μg U L^{-1})	150 (μg U L^{-1})	500 (μg U L^{-1})	1200 (μg U L^{-1})
Mean Exposure				
1	3.2×10^{-4}	3.2×10^{-2}	1.2×10^{-1}	2.6×10^{-1}
50 and 70	5.6×10^{-4}	5.8×10^{-2}	2.0×10^{-1}	4.8×10^{-1}
Maximum Exposure[a]				
1	6.8×10^{-4}	5.6×10^{-2}	2.0×10^{-1}	4.6×10^{-1}
50 and 70	1.2×10^{-3}	9.8×10^{-2}	3.4×10^{-1}	8.0×10^{-1}

[a]Maximum represents the 95th percentile

CONCLUSIONS

•U concentrations in vegetable crops irrigated with Nambe well water averaged 8 to 35 times higher than baseline crops.

•Dose estimates, based on water and vegetable ingestion and soil inhalation, indicate that exposure to well water containing up to 1200 μg U L^{-1} will not result in significant radiological health risks.

•U concentrations in the kidney did not exceed the 1 μg U g^{-1} kidney threshold for maximum exposure to Nambe well water containing up to 1200 μg U L^{-1}.

•The primary exposure pathway was found to be direct ingestion of well water, which resulted in over 99% of the radiological and toxicological dose to human consumers. This indicates that treating U in well water or utilizing other sources of drinking water will significantly reduce doses to Nambe area residents who are dependent on well water.

•The current limit proposed by the EPA is both very conservative and protective of the kidney under continuous long-term exposures based upon the assumption that the toxicity threshold of 1 μg U g^{-1} kidney and the most conservative safety factor (50) are valid.

ACKNOWLEDGEMENTS

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